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Extended Use of Night Vision Goggles: An Evaluation of Comfort for Monocular and Biocular Configurations

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Abstract

Forty-four military participants were tested in a field experiment to compare the relative discomfort experienced when monocular versus biocular night vision goggles (NVGs) were worn for an extended period of time. Participants traversed wooded terrain to reach various stations where they performed a variety of military and field craft tasks. The total test time was 4 hours. The participants rated their psychological and physiological feelings of discomfort at the completion of the test and again the following evening. Objective measures of NVG optical adjustments were also recorded.

The participants who wore the biocular goggle reported a higher incidence of tight neck muscles than did the participants who wore the monocular goggle. However, no other significant differences in discomfort were found that could be attributed to the ocular configuration of the goggles. All participants complained about discomfort from the head harness.

ACKNOWLEDGMENTS

We owe special thanks to Daniel Coates for providing night vision goggle training to the lane walkers and test participants. We also thank all other individuals who assisted with this study: Joe Casto, Steven Maxfield, Timothy Gentner, Timothy Grandison, David Hare, Mark Kregel, Barry Vaughan, and David White. We especially appreciate Ranger David Weissert, of the Broad Creek Memorial Boy Scout Reservation, whose generosity seems to be endless. Thanks are given to Nicky Keenan and Dennis Hash who constructed the stations, provided logistical support, and controlled the visual surveillance station. Finally, all the participants and the research personnel give special thanks to Mrs. Lillian Barnes for her outstanding contributions to this experiment.

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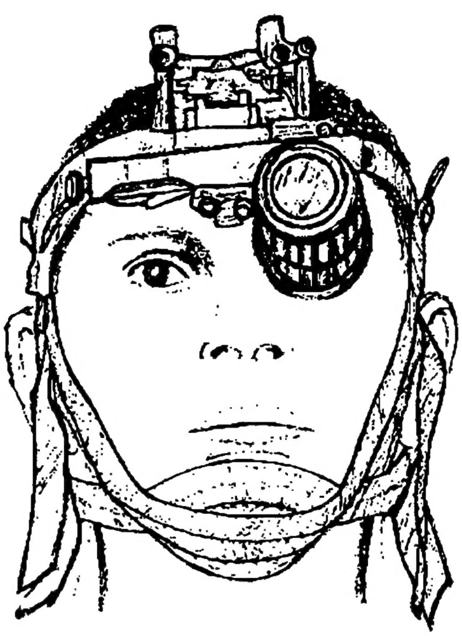
EXTENDED USE OF NIGHT VISION GOGGLES: AN EVALUATION OF COMFORT FOR MONOCULAR AND BIOCULAR CONFIGURATIONS

INTRODUCTION

Many military operations require individuals to work for prolonged periods of time in low illumination conditions. Night vision goggles (NVGs) have been worn during these operations to give individuals the opportunity to see what they would not be able to see with the unaided eye. Wearing any type of head-borne equipment for long periods of time is expected to affect the overall physiological and psychological comfort of the user. It is therefore paramount to ensure that those design configurations that may be particularly prone to problems are avoided. The purpose of this study was to determine if extended use of NVGs had a more pronounced effect on comfort for individuals who wore the monocular goggle than for individuals who wore the biocular goggle.[1] The two types of goggles are shown in Figure 1. We begin this report with a discussion of some of the relevant findings.



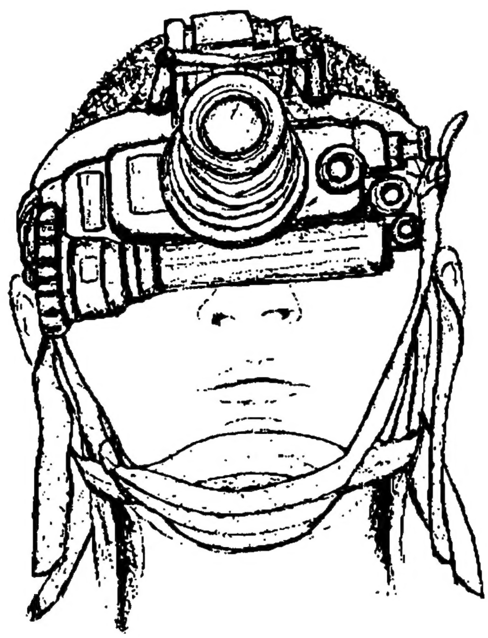


Figure 1. The head-mounted monocular and biocular goggles worn by the participants.

[1] A monocular configuration provides an intensified view of the environment to one eye, with the other eye having an unaided, naked eye, dark-adapted view. A biocular configuration allows both eyes to share the same two-dimensional (2D) intensified image of the environment.

A number of published studies and anecdotal reports indicate that comfort decreases as NVGs are worn for time periods longer than 1 hour. Stone and Duncan (1984) measured the psychomotor performance and the subjective opinions of helicopter pilots who wore goggles for three 2-hour periods in succession. They found that extended goggle use did not affect the pilots' psychomotor performance, but subjective levels of discomfort were notable. Participants reported eye fatigue, eye strain, and neck muscle strain, effects perhaps attributable to the weight of the goggles. Their participants also reported a decrease in concentration, interest in the task, and mental alertness.

Sheehy and Wilkinson (1989) also examined the effects of prolonged use of NVGs. The participants flew with NVGs for 1 to 4 hours. The major finding was a temporary reduction in depth perception. The researchers attributed this effect to a decreased ability of participants to resolve small amounts of retinal disparity with prolonged use of the NVGs and to improper adjustment of the NVG oculars for interpupillary distance.

CuQlock-Knopp, Torgerson, Sipes, Bender, and Merritt (1995) and CuQlock-Knopp, Sipes, Torgerson, Bender, and Merritt (1996) conducted experiments (two each at illumination conditions corresponding to no moon and 3/4 moon, respectively) requiring participants to traverse off-road terrain wearing monocular, biocular, or binocular NVGs. There were four experiments with a total of 71 participants tested. Visual comfort was one of the subjective dependent measures. Although the average time that the participants spent wearing the NVGs continuously was less than 30 minutes, the visual comfort results are of some interest. In three of the four experiments, the numerical rank for visual comfort was lower for the monocular goggle than for the other two types of goggles. In the remaining experiment, the monocular goggle was tied with the biocular goggle for the lowest rank.

The finding that prompted this research was from an Australian field test performed by Simmons (1994) using vehicle drivers. In this study, the drivers wore monocular, biocular, or binocular NVGs. On the day after testing, three of the ten participants who wore the monocular goggle for more than 1 hour reported migraine-type headaches. This finding generated an interest in determining if important differences in headaches and other aspects of visual discomfort would result from wearing the monocular or biocular goggles an extended period of time. A study was needed to determine whether these differences occur when the goggles are evaluated with the appropriate sample size and experimental controls. The study reported here was a field experiment to determine if extended NVG use produced any important differences in subjective indices of comfort for participants who wore the monocular goggle, compared with participants who wore the biocular goggle. (It is noted that the most recent Army NVGs developed for infantry use have

been either biocular or monocular.) Four measures of comfort were operationally defined as the composite of various subsets of ratings on bipolar scales of physiological and psychological attributes of well-being.

METHOD

Test Site

No-moon and full-moon experiments were conducted in the back country area of the Broad Creek Memorial Scout Reservation in Harford County, Maryland. The test area, which included sections of two camps (Camp Oest and Camp Cone), consisted of trails, meadows, woods of mixed deciduous and coniferous trees, woods of exclusively coniferous trees, ten man-made stations, and a variety of terrain hazards to foot travel, including drop-offs, side slopes, and holes.

A 2-kilometer course was developed for the experiment. White, 9-inch circular plates were mounted on trees along the course to mark the path from one station to another. A rectangular piece of black tape was affixed to the center of each plate to improve the participant's ability to see the plates against the forest background. The plates averaged 9 feet apart.

The course contained ten stations, spaced at various distances apart from each other. Figure 2 is a map of the test area, showing the appropriate location of the ten stations. Each station contained materials that were used to perform the tasks. For example, the "build lean-to" station contained large amounts of pre-cut limbs and bushes that were to be used to construct a lean-to. The tasks were designed to represent the types of activities that a soldier would perform during a night mission.

Experimental Design

A 2 (scene illumination level) x 2 (goggle type) between-subjects design was used for this experiment as shown in Table 1. Participants were randomly assigned to one of the four groups shown.[2]

[2] We planned to have 12 participants in each group. The last four participants failed to report for the study. The actual numbers of participants per group are denoted by the "N" value in each cell.

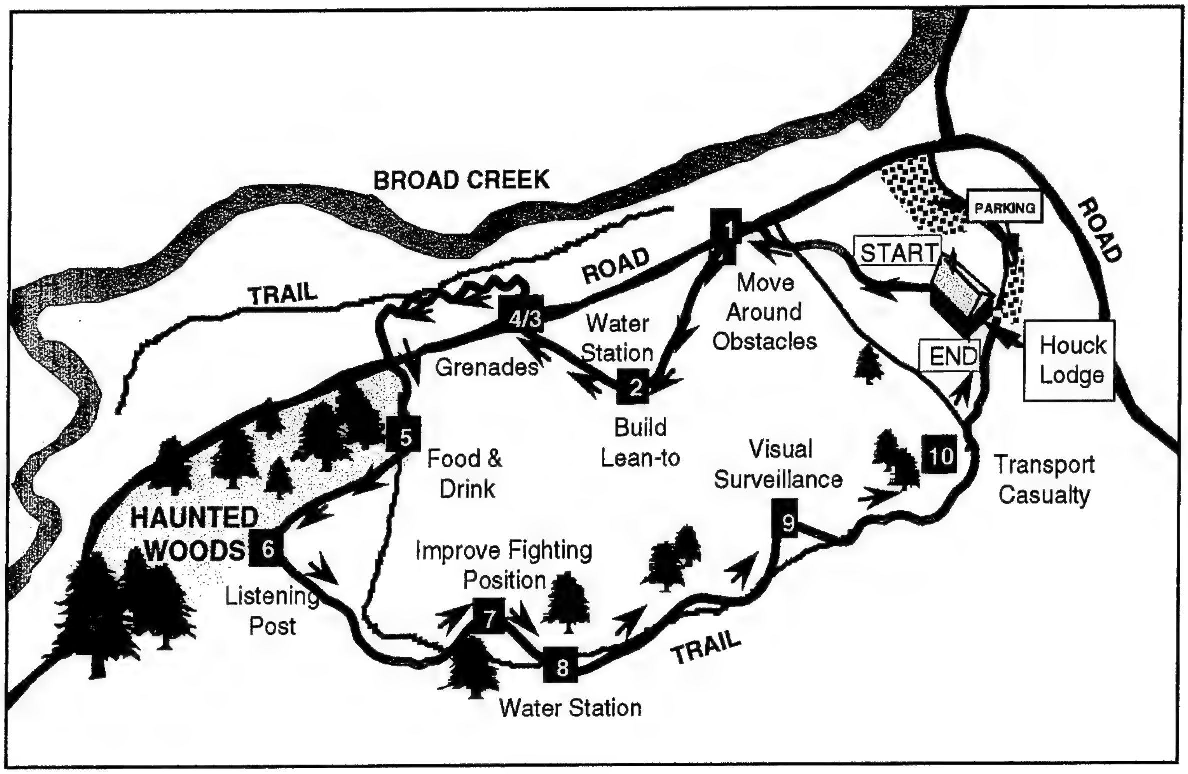


Figure 2. A map of the relative locations of the ten stations used in this experiment.

Table 1

The Experimental Design for the Extended Use Study

		GOGGLE TYPE	
		MONOCULAR	BIOCULAR
ILLUMINATION	NO MOON	N = 12	N = 12
	FULL MOON	N = 10	N = 10

Independent Variables

There were two independent variables in this study: goggle type and moon illumination. Monocular and biocular goggles were examined to determine if the ocular configuration of the NVGs produced differences in the measures of comfort after extended use. To allow for potential comparisons of this study's results with previous night vision goggle research, two groups of participants were tested on no-moon nights and two groups were tested on full-moon nights. For a previous study (CuQlock-Knopp et al., 1995), typical no-moon illumination nights near the site were measured to have an average illumination of 9.61×10^{-4} footcandles in an open area. Typical 3/4 moon illumination nights were measured to have an average light level of 5.70×10^{-3} footcandles in this same open area. In this experiment, however, no light readings were taken.

Dependent Variables

The dependent measures were the responses to four sets of questionnaire items presented on two separate questionnaires. These questionnaires are included as Appendices A and B. Questionnaire A contained items related to psychological and physiological well-being. Questionnaire B contained items that related exclusively to physiological well-being.

Dependent Variable 1: Fatigue

Variable 1 was the average of each participant's ratings of factors related to fatigue that might be associated with wearing NVGs for an extended period of time. The first item reflected the participant's rating of whole body fatigue; the second item reflected his rating of eye fatigue, and the third reflected his rating of neck muscle fatigue.

Dependent Variable 2: Annoyance

Variable 2 was the average of the participant's ratings of the annoying factors associated with wearing the goggles over an extended period. The first item reflected the participant's rating of annoyance elicited by sweat irritation; the second reflected annoyance elicited by fogging goggles or fogging safety glasses, and the third reflected annoyance elicited by heat. These ratings comprised Items 4 through 6 of Questionnaire A.

Dependent Variable 3: Mental Alertness

Variable 3 was the average of the participant's ratings of how the goggles affected comfort with regard to mental alertness. The first item reflected the participant's rating of concentration, the second item reflected attention, and the third item reflected boredom. These ratings comprised Items 7 through 9 of Questionnaire A.

Dependent Variable 4: Physiological Comfort

Five items were used to reflect aspects of physiological comfort: blurred vision, headaches, eye strain, tight neck muscles, and stiffness of the whole body. The items for this variable comprised Questionnaire B.

Predictor Variable

The last variable, a predictor variable, was an index of the participant's visual accommodation, as measured by the focus setting on the back end (the eyepiece) of the goggle. This measure was recorded using a diopter scope before the participant went to the first station and after he returned to the lodge after finishing the course.

PARTICIPANTS

Test Participants

Forty-four Maryland National Guardsmen (all male) between the ages of 20 and 45 served as participants. The participants were required to have at least 20/40 acuity (corrected or uncorrected) in both eyes and to be available the evening after testing for a telephone interview. Additionally, the participants were required to wear their pistol belt with canteen, combat boots, and summer battle dress uniform (BDU).

Lane Walkers

Half of the six lane walkers were National Guardsmen and the other half were psychology graduate students. All lane walkers were physically fit and trained in the use of NVGs. Each was responsible for following the test participant as he proceeded from one station to the next station. The lane walker ensured that the participant completed the designated task at each station, but he did not record any qualitative data about how the task was completed.

The lane walker also had an enforcement role. He made sure the participant did not go to the next station before the station duration time had elapsed. He also made sure that the participant did not remove or turn off his goggles unless the participant chose to discontinue participation in the experiment. Each lane walker wore a third generation NVG for this experiment.

Interviewer

The interviewer was responsible for administering the questionnaires to the participants.

APPARATUS

Night Vision Goggles

The two types of NVGs used for this study were essentially identical in field of view (40° circular), resolution (0.8 cycle per milliradian), and magnification (1X). The biocular goggle was the AN/PVS-7B night vision goggle. The monocular goggle was an aviator's night vision imaging system (ANVIS) with one ocular removed, so that the remaining ocular corresponded to the eye that the participant selected to use for the goggle (i.e., the preferred eye). The monocular goggle was retrofitted so that it could use the same head mount as the biocular goggle.

The battery pack for the monocular goggle was affixed to the goggle shelf. The biocular goggle had an integral battery compartment. The total head-borne weights for the two types of goggles were monocular, 514 grams and biocular, 695 grams. No eyecups were used on any of the goggles. Standard AA batteries were used; batteries were replaced at the beginning of each night of testing. Figure 1 depicts the two types of goggles as worn by the participants.

Inanimate Targets

Ten silhouette figures dressed in summer BDUs were placed along the way from one station to another. The BDU clothing was stuffed with plastic bubble wrap to fill the body of the target. An 11th silhouette target was placed outside the lodge for the participant to observe before proceeding to the first station. A 12th silhouette was used at the ninth of the ten stations.

Communication Devices

Two-way radios were used to allow the lane walkers and the base camp attendants to communicate with each other in case of an emergency or if assistance was required at one of the stations. The radio also allowed the lane walker to ensure the stations were clear for testing when the lane walker arrived with the participant.

PROCEDURES

Preliminary

The lane walkers were first trained by one of the principal investigators in the scoring and timing procedures used during the test. During this training, she told the lane walker the purpose of the experiment and how to ensure that the participant was complying with the requirements of this study. The main rules emphasized were (a) participants must not remove the goggles, (b) participants must attempt to complete each task, and (c) participants must spend the designated time at each station.

Each of the lane walkers traversed the area covering the ten stations in the daylight to ensure his knowledge of the terrain. The lane walker memorized the standard of performance for each station. He also completed each task so that he could be confident in his instruction of the participants. Two practice tests were then completed to ensure that the lane walkers had extensive experience in scoring and timing the participants and to determine the adequacy of the testing procedures.

Testing Procedures

When each participant arrived at the base camp lodge, he was screened for at least 20/40 visual acuity using a Snellen chart. If the participant passed the vision test, he was then asked to read and sign a consent form. His hearing was also tested.[3] The experimenter then discussed the purpose of the experiment and read the standards of performance for each of the tasks to be performed at the ten stations.[4]

Table 2 lists the ten military, field craft, experimental, or relaxation tasks that the participants were asked to complete during this experiment. The tasks performed at Stations 1, 4, 7, 9, and 10 were military tasks taken from the Soldier's Manual of Common Tasks, Skill Level 1 (Headquarters, Department of the Army, 1994). The participants were required to perform a field craft task at Station 2 and were required to perform an auditory experiment at Station 6. Stations 3, 5, and 8 were designed to provide rest for the participants. The standard of performance of these tasks and the time allocated for completion of each are listed in Appendix C.

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[3] This infomation was used to supplement the data collected at the listening post and was not used for the present study.

[4] The specific tasks were chosen because they represent some of the types of activities an infantryman would perform while wearing goggles for prolonged periods of time.

Table 2

The Ten Stations Used for the Extended Use Study

Station 1	Move over, through, or around obstacles
Station 2	Build a lean-to shelter
Station 3	Water station
Station 4	Employ mock hand grenades
Station 5	Food and drinks station
Station 6	Listening post station
Station 7	Improve hasty fighting position
Station 8	Water station
Station 9	Performance visual surveillance
Station 10	Transport a casualty using a one-man carry

Next, a different experimenter presented an extensive safety briefing about precautions to be taken for traversing off-road wooded areas at night and procedures for protecting oneself against ticks, snakes, and dehydration.

The participant then went to a room where the lighting was kept low enough to permit him to adapt to the dark. He donned either the monocular or the biocular goggle, depending on his group assignment. The participant assigned to the monocular goggle group was asked to try the left-eye or right-eye monocular goggle and then asked to choose which goggle he preferred to wear. Eye preference was noted by the experimenter. This participant was also given a pair of safety glasses with the lens removed, corresponding to the eye aided by the goggles.

At this time, the participant was given an extensive briefing about adjusting and focusing the goggles.[5] The participant then went outside where he used a second Snellen vision chart to check and readjust, if necessary, the focusing of the goggle. He returned inside the lodge where a diopter scope was used to measure where he had focused the eyepiece on the goggles. This procedure is described in detail in Appendix D.

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5 The participants were instructed to focus the goggles by first turning each eyepiece counterclockwise (i.e., toward more positive diopters) until the image was blurred, and to then reverse direction (to more negative diopters) until the image became sharply focused.

Next, the participant followed his assigned lane walker outside where he was shown a human silhouette target dressed in BDU. The participant was told to look for and report any detections of targets such as this silhouette seen while traveling from one station to another.

The participant then followed his lane walker to a section of the camp where the participant's depth perception was estimated.[6] After that, the participant and the lane walker proceeded to Station 1. The lane walker started a stopwatch when the participant reached this station and reminded the participant of the time (in this case, 10 minutes) that he had to complete the task. The lane walker also re-stated the same task standard for the station that the participant first heard when he received his initial instructions from the principal investigator inside the lodge. At this time, the lane walker told the participant to begin the task.

If the participant finished the task before the station duration time had elapsed, he was required to wait until it had. If the participant had not completed the task when the time elapsed, he was told to proceed to the next station anyway. To guard against overlapping participants at the stations, however, two essentially identical work sites were established at each of the stations.

When the participant arrived at Station 2, the lane walker again started his stopwatch and reminded the participant of the allocated station time and task standard. The total time required to complete the ten stations was 180 minutes. In addition, 10 minutes were allowed for the depth perception test and 50 minutes for walking time.

After finishing the tenth station, the participant returned to the lodge where another measurement was taken to record where he had focused the eyepiece on the goggle. In addition, a measurement was also taken to determine where the participant had the objective lens focused (the range focus).

Each test participant had been cautioned not to change either the range focus setting (NVG objective lens) or the NVG eyepiece settings at the end of the course run, when he entered the lodge. When the participant entered the lodge, he was asked to stand 22 ft (6.7 m) from an eye chart in the lodge. Plus and minus corrective lenses (optometric trial lenses) were then used to determine the focus distance setting (range focus) of the NVG objective lens. The procedure used is described in Appendix E.

The dioptric settings of the NVG eyepieces were measured using a "diopter scope" and a prototype hand-held device for projecting a collimated bar target image onto the NVG. The

[6] These depth perception data were used for another study.

existing eyepiece diopter values were obtained by adjusting the diopter scope's eyepiece until the NVG image of the bar target was in sharp focus.

The participant then completed Questionnaires A and B to record his subjective ratings of his state of well-being. The participant was given another copy of Questionnaire B to take home. The participant then left the camp. The test sequence for the test night is given as Appendix F.

Participants' start times were staggered by 20-minute increments. Six different participants were tested on each night.

The next evening, the participant was again required to respond to Questionnaire B. This time, his response was recorded by an interviewer who read each Questionnaire B item by telephone and recorded the participant's ratings. Each participant was paid $110.00 to cover his test participation during the two nights. These field experiments were conducted during the last week in July and during the second week in August 1995.

RESULTS

Psychological and Physiological Symptoms

Separate 2 x 2 analyses of variance (ANOVAs) were performed for each of the four dependent measures to determine if the (a) measures of comfort were significantly different for the monocular and biocular goggles, (b) comfort measures were different during full-moon illumination nights than during no-moon illumination nights, and (c) effect of goggle type on comfort depended on moon illumination (i.e., the interaction).[7] All summary tables are given in Appendix G.

Table 3 depicts the "fatigue" composite variable, which included a combination of the participant's rating of whole-body fatigue, his rating of eye fatigue, and his rating of neck muscle fatigue. The ANOVA of the fatigue variable indicated no significant effects: goggle, $F(1, 2) = .00$, $p > .05$, moon, $F(1, 2) = .66$, $p > .05$, and the Goggle x Moon interaction, $F(1, 2) = .48$, $p > .05$.[8]

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[7]During this experiment, the participant had the opportunity to detect 10 targets. The target-detection measure was of no direct interest to the objective of this study. The following is provided as supplementary information. A goggle x moon ANOVA was performed using number of targets detected as the dependent variable. The results indicated that participants detected significantly more targets in the full-moon condition than in the no-moon condition, $F(1, 2) = 8.67$, $p = .005$. The goggle main effect and the Goggle x Moon interaction were statistically insignificant.

[8]In the general logic of hypothesis testing, the null hypothesis states that there are no treatment effects in the population of people (i.e., infantrymen in the U.S. Army) from which a sample of subjects for a particular experiment was drawn (see Keppel, 1992, Chapter 2). In this experiment, we have established $p < 0.05$ (probability

Table 3

Fatigue

	Monocular		Biocular	
	$\bar{x}$	σ	$\bar{x}$	σ
No moon	3.44	1.01	3.69	1.05
Full moon	3.40	1.43	3.13	1.46

Table 4 depicts the "annoyance" composite variable, which included the participant's rating of sweat irritation, his rating of fogging goggles or glasses, and his rating of heat annoyance. The ANOVA of the annoyance variable indicated no significant effect of goggle $F(1, 2) = .51, p > .05$. Unlike the fatigue variable, this ANOVA indicated that participants were more annoyed during the no-moon nights than during the full-moon nights, $F(1, 2) = 6.47, p = .01$. The Goggle x Moon interaction was not significant, $F(1, 2) = .15, p > .05$.

Table 4

Annoyance

	Monocular		Biocular	
	$\bar{x}$	σ	$\bar{x}$	σ
No moon	3.19	1.69	3.03	1.02
Full moon	2.30	1.44	1.90	.92

is less than 0.05) as the criterion for rejecting the null hypothesis. For the *goggle* main effect of the fatigue composite variable, the $p > .05$ indicates that the probability of observing an F value of .00, based solely on chance factors, is greater than five times in 100. Given our criterion of $p < 0.05$, we cannot reject the null hypothesis that the means in the population are equal.

In experimental work, it is traditional to assume that there will be no effect of the treatment (null hypothesis), and then the experiment attempts to disprove this assumption (i.e., to reject the null hypothesis). A p less than 0.05 means that if the experiment were repeated 100 times, the results that would be obtained would occur fewer than 5 times of 100 simply by chance.

Table 5 depicts the "mental alertness" composite variable, which included the participant's ratings of concentration, his rating of distraction, and his rating of boredom. The ANOVA of mental alertness revealed no significant effects: goggle, $F(1, 2) = .58, p > .05$, moon, $F(1, 2) = .14, p > .05$, and the Goggle x Moon interaction, $F(1, 2) = .14, p > .05$.

Table 5

Mental Alertness

	Monocular		Biocular	
	$\bar{x}$	σ	$\bar{x}$	σ
No moon	2.50	1.49	3.00	1.15
Full moon	2.83	1.45	3.00	1.70

Physiological Symptoms

The physiological symptoms listed in Table 6 were obtained from Questionnaire B. Questionnaire B was completed on the test night and again on the next evening between 1800 and 2000 hours. The mean rating for each questionnaire item is provided separately and recorded in Table 6 for both the test night and for the next evening.

Separate ANOVAs were conducted on each Questionnaire B item that was completed during the test night and during the next evening. These 10 analyses indicated only two significant effects. The first effect was the discomfort attributed to tight neck muscles for the test night. The biocular goggle participants reported more discomfort because of tight neck muscles than did the monocular goggle participants. (The biocular NVG weighed 695 grams, which was about half a pound more than the monocular NVG, which weighed 514 grams.)

The second significant effect was related to the moon illumination variable. Participants who were tested during full-moon nights reported more eye strain on the next day after testing than did those tested during no-moon nights.

Table 6

Physiological Symptoms

		Test night		*Next evening*	
		Monocular	Biocular	Monocular	Biocular
Blurred vision					
	No moon	2.40	1.70	1.17	1.17
	Full moon	2.40	2.00	1.40	1.30
Headaches					
	No moon	1.70	2.20	1.30	1.08
	Full moon	2.10	1.70	1.70	1.60
Eye strain					
	No moon	2.20	2.90	1.20	1.20
	Full moon	2.60	2.50	2.00	1.70
Tight neck muscles					
	No moon	1.80	3.25	1.60	1.90
	Full moon	2.60	3.00	2.20	1.80
Stiff whole body					
	No moon	1.40	2.16	1.50	1.30
	Full moon	2.70	2.30	1.90	2.10

Correlations Among Symptoms

Table 7 contains the Pearson correlation coefficients among the physiological symptoms of discomfort occurring on the test night. The following statistically significant correlations were found: (a) eye strain with blurred vision, (b) headaches with eye strain, (c) stiff whole body with headaches, and (d) stiff whole body with tight neck muscles.

Table 8 contains the Pearson correlation coefficients among the physiological symptoms reported the next evening. Only one correlation (eye strain with headaches) was significant.

Table 7

Correlation Matrix of Physiological Symptoms of Discomfort
(test night)

	Blurred vision	Headaches	Eye strain	Tight neck muscles	Stiff whole body
Blurred vision	1	.24	.60**	.16	.17
Headaches		1	.46*	.33	.48**
Eye strain			1	.23	.39
Tight neck muscles				1	.51**
Stiff whole body					1

* = $p < .05$ ** = $p < .001$

Table 8

Correlation Matrix of Physiological Symptoms of Discomfort
(next evening)

	Blurred vision	Headaches	Eye strain	Tight neck muscles	Stiff whole body
Blurred vision	1	.06	.34	.26	.10
Headaches		1	.67**	-.10	-.04
Eye strain			1	.21	-.03
Tight neck muscles				1	.33
Stiff whole body					1

** = $p < .001$

EYEPIECE LENS SETTINGS

A "diopter scope" was used to measure the dioptric settings of the NVG eyepieces. We wish to stress that the eyepiece diopter readings show only how the NVG eyepieces were set by the participants and have no relation to the focus distance of the NVG objective (front) lens that

imaged the real world onto the NVG image intensifier. Table 9 shows the eyepiece diopter setting data before and after the course run.

Table 9

Means of Eyepiece Diopter Settings

		MONOCULAR		BIOCULAR	
		LEFT	RIGHT	LEFT	RIGHT
BEFORE	$\bar{x}$	-1.57	-1.37	-1.66	-1.43
	σ	1.05	.87	1.19	.77
AFTER	$\bar{x}$	-1.71	-1.79	-1.53	-1.64
	σ	1.1	.92	.98	.84
		N=11	N=11	N=22	N=22

Predictor Dependent Variable

Pearson product moment correlations were calculated to determine if there were any correlations between visual accommodation (as measured by these diopter settings) and headaches. These correlations are shown in Table 10. There were no statistically significant correlations between headache data and eyepiece diopter data. Table 11 shows the Pearson product moment correlations for visual accommodation and blurred vision, and Table 12 shows the Pearson product moment correlations for visual accommodation and eye strain. Again, there were no statistically significant correlations.

Table 10

Correlations Between Headaches and Eyepiece Diopter Settings

		MONOCULAR		BIOCULAR	
		LEFT	RIGHT	LEFT	RIGHT
BEFORE	First Day	.33	.13	-.04	.14
	Next Day	.41	.22	.23	.21
AFTER	First Day	-.33	.09	.03	.20
	Next Day	-.01	-.25	.36	.32

Table 11

Correlations Between Blurred Vision and Eyepiece Diopter Settings

		MONOCULAR		BIOCULAR	
		LEFT	RIGHT	LEFT	RIGHT
BEFORE	First Day	-.12	.34	-.05	-.20
	Next Day	.40	.38	.10	.09
AFTER	First Day	-.15	.01	.01	-.25
	Next Day	.43	.36	.16	.17

Table 12

Correlations Between Eye Strain and Eyepiece Diopter Settings

		MONOCULAR		BIOCULAR	
		LEFT	RIGHT	LEFT	RIGHT
BEFORE	First Day	.16	.01	-.16	-.36
	Next Day	.42	.47	.24	.22
AFTER	First Day	.04	-.21	-.19	-.39
	Next Day	.17	.54	.35	.34

Objective Lens Focus Distance Settings

After each participant completed the course, a set of optometric corrective lenses was used to determine his focus distance setting of the NVG objective lens (i.e., the NVG front lens). This was done to obtain data about the distribution of typical focus distance settings. In doing the calculations of NVG objective lens focus distance settings, the actual measured values of the corrective lenses were used, not their nominal values stamped on the lenses.

In Figure 3, negative diopter values do not have a practical significance as a distance in feet, and so the symbols " > ∞" are placed at the top of the columns for negative diopter values. The tolerance for the setting focus is estimated to be ± .05 diopter. Figure 3 shows the objective lens focus distance settings for the monocular participants and for the biocular participants.

Questionnaire C

Each lane walker wore the goggles for 4 hours every night for 8 nights. Each lane walker could provide opinions based on 32 hours of NVG use; therefore, we developed Questionnaire C (see Appendix H) to obtain additional information about discomfort. However, in this case, we were more direct about the focus of our questions than with the test participants. We asked the

lane walker to name the source of the discomfort and, if appropriate, to state what caused any headaches.

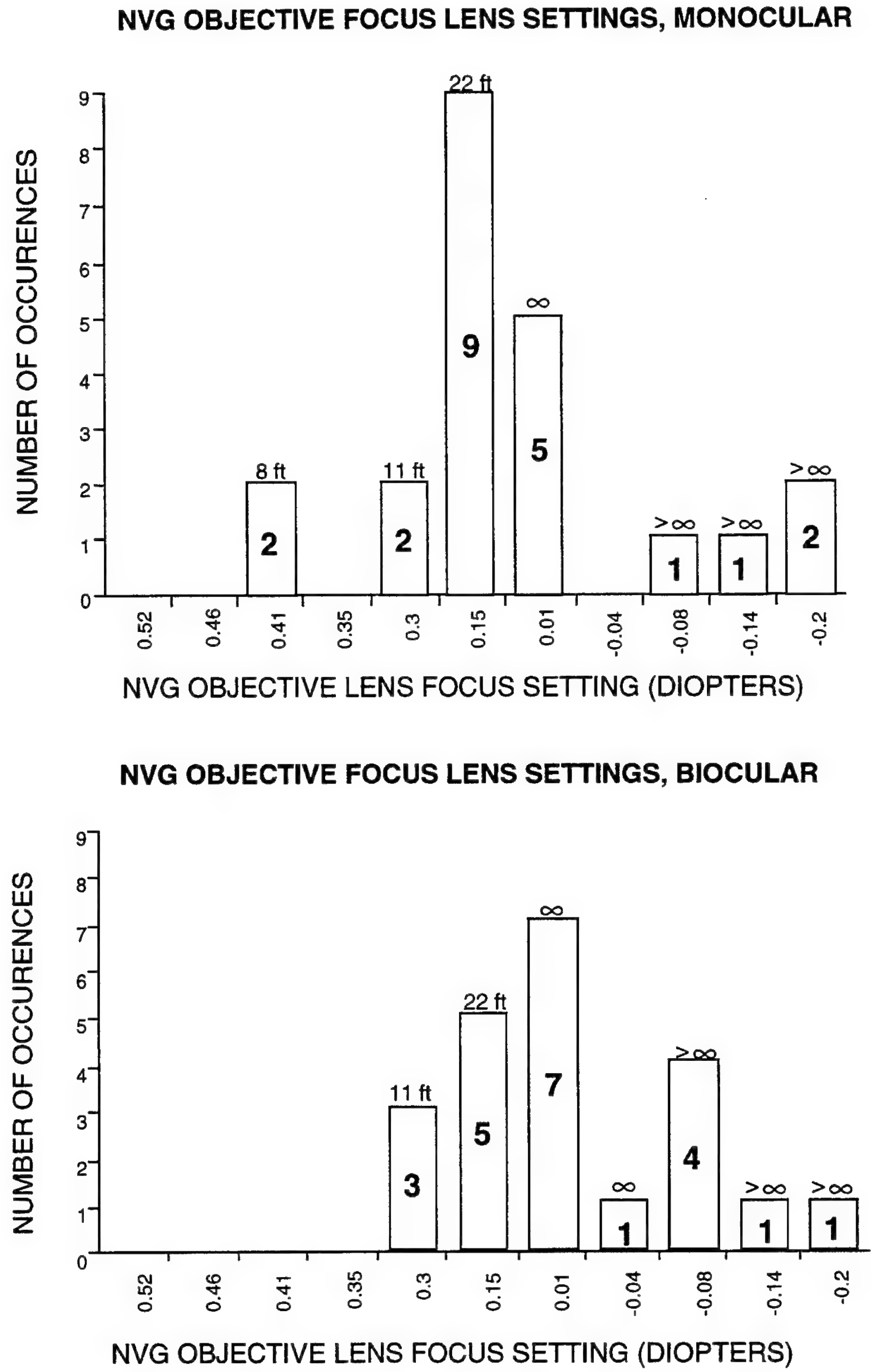

Figure 3. Objective lens focus distance settings.

All the lane walkers reported that the head harness was the source of their discomfort while they wore the goggles. They complained that the head harness put too much pressure on the chin and temple. The lane walkers also all agreed that this problem was independent of the type of goggle (monocular or biocular) worn.[9]

DISCUSSION

The objective of the study was to determine if extended NVG use produced any important differences in subjective indices of discomfort for participants who wore the monocular goggle compared with participants who wore the biocular goggle. The results of this study show no important differences in comfort between the monocular and biocular NVGs. In every case, the statistically significant differences that occurred could be explained by factors other than the ocular configuration of the goggles. It is important for the reader to note that a rating of "4" was the midpoint of the bipolar rating scale used in this experiment to obtain the discomfort measure. A rating of "1" reflected discomfort that was not noticeable, and a rating of "7" reflected discomfort that was severe.

The only statistically significant difference in discomfort as a function of goggle type was for tight neck muscles. This effect can easily be attributed to the 180-gram difference in weight between the biocular and the monocular goggles. However, even though this significant difference between the two goggles was found, the highest mean in the 2 x 2 table of discomfort for tight neck muscles is 3.25, below the midpoint of the discomfort scale.

The other two significant differences involved moon illumination. An examination of the individual items of annoyance indicated that the participants were more annoyed by perspiration during no-moon nights than during full-moon nights. Testing was conducted in the summer, and records of temperature during the 2 weeks of testing revealed a difference of 10° (Fahrenheit), with the higher temperatures occurring during the no-moon nights. The effect of moon illumination on eye strain the next day, although statistically significant, is of little substantive importance since the mean rating values fell between the "not noticeable at all" and the next lowest category.

The high correlation between headaches and eye strain is not surprising since eye strain is often considered to be a major cause of headache. Stiff whole body and tight neck muscles are

[9]Of the 48 times (six lane walkers x eight nights) that lane walkers wore the NVGs, the biocular goggle was worn 32 times and the monocular goggle was worn 16 times. Three of the lane walkers always chose to wear the biocular goggle. The other three wore the biocular goggle some nights and the monocular goggle other nights.

also symptoms that would be expected to be related to each other, as is the relation between stiff whole body and headaches.

The eyepiece data were collected because there was some conjecture that a pattern of visual accommodation could provide some rationale for the cause of headaches, if the headaches occurred. The results of the correlational analyses indicated that neither headaches, eye strain, or blurred vision were significantly correlated with eyepiece diopter settings.

A clear finding in this study is that all instances of headaches reported during the study were attributable to the head harness. This finding is noteworthy for a number of reasons. For one, Bui (personal communication, 1995) administered a survey to 49 NVG users for the 82nd Airborne at Ft. Bragg, North Carolina. Her survey responses indicated that the harness was one of the main features of the NVG that the participant would like to see improved. Two, the Australian study that prompted the present study also indicated that the harness was very uncomfortable. Three, in our study, the last item of Questionnaire B elicited remarks concerning how the participant was feeling; most of the participants reported extreme discomfort because of the head harness. The lane walkers, who were asked directly about headaches, also attributed head pain to the head harness. What is not clear is whether this head pain was internal, as from a headache, or external, as from too much pressure on the chin or temple. In either case, it seems that harness discomfort is a pervasive problem and remains a limiting factor in the extended use of some types of NVGs.

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APPENDIX A

QUESTIONNAIRE A

QUESTIONNAIRE A

Rate your whole-body fatigue.

1 2 3 4 5 6 7
(small amount) (very fatigued)

Rate your eye fatigue.

1 2 3 4 5 6 7
(small amount) (very fatigued)

Rate your neck-muscle fatigue.

1 2 3 4 5 6 7
(small amount) (very fatigued)

How much annoyance do you feel from sweat irritation?

1 2 3 4 5 6 7
(small amount) (very annoyed)

How much annoyance do you feel resulting from fogging glasses or the fogging eye piece on the goggle?

E = eye piece
G = glasses

1 2 3 4 5 6 7
(small amount) (very annoyed)

How much annoyance do you feel resulting from heat?

1 2 3 4 5 6 7

(small amount) (very annoyed)

How has the extended use of the goggles affected your concentration?

1 2 3 4 5 6 7

(focused) (very distracted)

How has the extended use of the goggles affected your attention?

1 2 3 4 5 6 7

(attentive) (cannot concentrate)

How has the extended use of the goggles affected your interest in the task?

1 2 3 4 5 6 7

(very interested) (bored)

APPENDIX B

QUESTIONNAIRE B

QUESTIONNAIRE B

Rate the severity of each symptom you may be experiencing.

Blurred vision

1	2	3	4	5	6	7
(not noticeable)						(severe)

Headaches

1	2	3	4	5	6	7
(not noticeable)						(severe)

Eye strain

1	2	3	4	5	6	7
(not noticeable)						(severe)

Tight neck muscles

1	2	3	4	5	6	7
(not noticeable)						(severe)

Stiff whole body

1	2	3	4	5	6	7
(not noticeable)						(severe)

For each time frame, write the number of times you wore night vision goggles; enter zero if you did not wear goggles during the time frame.

__ I wore goggles in July 1995.

__ I wore goggles in June 1995.

__ I wore goggles within the last year, but not since May 1995.

__ I wore goggles more than 1 year ago.

Do you have any remarks about the way you are feeling that you would like to report?

(Use the other side of the page if necessary.)

APPENDIX C

TASK STANDARDS

TASK STANDARDS

	STATIONS	STANDARDS	TIMES
1	(Move over, through or around obstacles)	Follow the plates to Station 1 and negotiate each obstacle encountered.	8 min.
2	(Build a lean-to shelter)	Near two designated trees, tie a small log horizontal between the trees about 3 feet from the ground. Tie two additional small logs, each of the same length, from the points where the horizontal log is butted against the tree to the ground. Lay branches from the designated pile across these two logs to form a roof surface.	30 min.
3	(Water station)	Sit, rest, and drink water.	10 min.
4	(Employ mock hand grenades)	Stand at designated point. Throw each of the 5 grenades, one at a time, through the window. Find and return the five grenades to the box.	7 min.
5	(Food and drinks station)	Sit, rest, drink & snack; walk to the rest room.	30 min.
6	(Listening post station)	Listen to experimenter's directions.	25 min.
7	(Improve hasty fighting position)	Construct a hasty fighting position using sand bags to provide frontal cover. Allow yourself space to fire from the front and side. Use all the sand bags present in the designated area. Return all sand bags to the original position.	20 min.
8	(Water station)	Sit and relax and drink water.	25 min.
9	(Performance visual surveillance)	Scan area for stationary and moving targets. Report targets to the lane walker.	15 min.
10	(Transport a casualty using a one-man carry)	Transport the casualty to the designated area using a one-man, Fireman's carry. Return the casualty to the original location.	10 min.

APPENDIX D

METHOD FOR DETERMINING DIOPTER SETTING OF THE NVG EYEPIECE LENS (BACK LENS) AT END OF EACH RUN

METHOD FOR DETERMINING DIOPTER SETTING OF THE NVG EYEPIECE LENS (BACK LENS) AT END OF EACH RUN

After the NVG focus distance setting was determined using corrective lenses, as described in Appendix E, a "diopter scope" was used to measure the dioptric settings of the NVG eyepieces. A prototype hand-held projector of a collimated bar target image was placed at the input of the NVG. The eyepiece diopter values were obtained by adjusting the diopter scope's eyepiece until the NVG image of the bar target was in sharp focus. For each eyepiece, two diopter scope readings were averaged to produce the eyepiece diopter data listed in the report.

These eyepiece diopter readings show only how the NVG eyepieces were set by the participants, presumably to compensate for their own ocular characteristics; they have no relation to the focus distance data of the NVG objective (front) lens that images the real world onto the image intensifier.

APPENDIX E

METHOD FOR DETERMINING FOCUS DISTANCE SETTINGS OF THE NVG OBJECTIVE LENS (FRONT LENS) AT END OF EACH RUN

METHOD FOR DETERMINING FOCUS DISTANCE SETTINGS OF THE NVG OBJECTIVE LENS (FRONT LENS) AT END OF EACH RUN

OBJECTIVE LENS

After each test run through the woods, a procedure employing test lenses was used to determine the focus distance setting of the NVG objective lens (NVG front lens). Each test participant was cautioned not to change either the range focus setting (NVG objective lens) or the NVG eyepiece settings at the end of the course, when he entered the cabin. The participant then stood 22 ft (6.7 m) from an eye chart in the cabin. Plus and minus corrective lenses (ophthalmic trial lenses in 0.12 diopter steps) were used to determine the focus distance setting (range focus) of the NVG objective lens by trying different lenses and asking the participant which combination of lenses made the eye chart image sharper, using the following procedure:

The weakest negative lens (-0.12 diopter) was placed over the NVG objective lens, and the participant was asked if this made the eye chart look sharper. If not, the procedure branched to the weakest positive lens (+0.12 diopter), placed over the NVG objective lens, and again the participant was asked if this made the eye chart look sharper. If the first minus lens improved the target sharpness, then the next stronger minus lens was tried, and so on, until a lens was found that provided no further improvement in eye chart sharpness.

If none of the corrective lenses improved the eye chart sharpness, the value of "zero" was recorded, which meant that the NVG objective lens focus distance had been set at 22 ft. If one of the plus or minus corrective lenses improved the eye chart sharpness, then the diopter value of that lens was recorded and from this diopter value, the focus distance of the NVG objective lens was inferred, using the method described below:

The focus distance (range focus) setting of the NVG objective lens was calculated as follows:

Dioptric distance of eye chart at 22 ft = 1 / 6.706 m

Dioptric distance of eye chart at 22 ft = 0.1491 diopters

Objective lens diopters = Corrective lens diopters - 0.1491

Focus distance (m) = 1 / (objective lens diopters)

Focus distance (ft) = Focus distance (m) / 0.3048

Therefore, the range focus distance (ft) of the NVG objective lens was given by

FD (ft) = 1 / ((corrective diopters - 0.1491)* 0.3048)

Example: if a corrective lens diopter value of +0.1491 gave the best sharpness of the eye chart viewed at 22 ft, then the NVG objective must have been focused at infinity (zero dioptric distance), because it took a plus corrective lens of 0.1491 diopter, added like a zoom lens to the NVG objective lens, to bring the eye chart at 22 ft into sharpest focus, which is a dioptric distance of 0.1491 diopter).

Corrective lens data that exceed +0.1491 diopter indicate that the NVG objective lens was focused "beyond" optical infinity. There were 10 instances of focus settings beyond infinity focus, but none of these exceeded infinity by more than 0.25 diopter. As a reference, it is estimated that the user's accuracy in focusing the objective lens is $\pm$ 0.05 diopter (McLean, 1996).

Corrective lens data in the minus diopter values indicated that the NVG objective lens had been focused for a distance closer than the 22-ft eye chart distance. (For example, using the formulas given, a -0.25-diopter corrective lens indicated that the NVG objective lens had been focused for a distance of 8 ft.)

In doing the calculations of NVG objective lens focus distance settings, the actual measured values of the corrective lenses were used, not their nominal values stamped on the lenses. This accounts for the slight variations in calculated focus distances shown as a function of the nominal corrective lens values.

APPENDIX F

SEQUENCE OF TEST SESSION

SEQUENCE OF TEST SESSION

START

INSIDE LODGE

1. Participants arrive and Snellen & Hearing tests administered.
2. Participants sign Volunteer Agreement form.
3. Purpose of Experiment and Task Standards explained.
4. Safety Brief.
5. Adjust & focus goggle procedures indoors.

OUTDOORS

6. Adjust & focus goggle procedures outdoors.

INSIDE LODGE

7. Diopter settings recorded.

OUTDOORS

8. Depth perception test with goggles.
9. Tasks at stations.
10. Objective lens setting & diopter settings recorded.
11. Questionnaires A & B[1] administered.

STOP

[1] Questionnaire B was repeated the next evening after testing.

APPENDIX G

ANALYSES OF VARIANCE

ANALYSES OF VARIANCE

Analysis of Variance
(Fatigue)

Tests of Significance for FATIGUE Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	1.001	2	.500	.329	.722
GOGGLE	.001	1	.001	.000	.982
MOON	1.000	1	1.000	.657	.422
2-Way Interactions					
GOGGLE MOON	.728	1	.728	.479	.493
Explained	1.731	3	.577	.379	.768
Residual	60.843	40	1.521		
Total	62.573	43	1.455		

Analysis of Variance
(Annoyance)

Tests of Significance for ANNOYANCE Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	12.029	2	6.014	3.487	.040
GOGGLE	.876	1	.876	.508	.480
MOON	11.153	1	11.153	6.467	.015
2-Way Interactions					
GOGGLE MOON	.148	1	.148	.086	.771
Explained	12.120	3	4.040	2.343	.088
Residual	68.981	40	1.725		
Total	81.101	43	1.886		

Analysis of Variance
(Mental Alertness)

Tests of Significance for MENTAL ALERTNESS Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	1.515	2	.758	.361	.699
GOGGLE	1.212	1	1.212	.578	.452
MOON	.303	1	.303	.144	.706
2-Way Interactions					
GOGGLE MOON	.303	1	.303	.144	.706
Explained	1.942	3	.647	.308	.819
Residual	83.944	40	2.099		
Total	85.886	43	1.997		

Analysis of Variance
Blurred Vision Test Night

Tests of Significance for Blurred Vision Test Night Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	3.880	2	1.940	.947	.397
GOGGLE	.273	1	.273	.133	.717
MOON	3.607	1	3.607	1.760	.192
2-Way Interactions					
GOGGLE MOON	.334	1	.334	.163	.689
Explained	4.448	3	1.483	.723	.544
Residual	81.983	40	2.050		
Total	86.432	43	2.010		

Analysis of Variance
Blurred Vision Next Evening

Tests of Significance for Blurred Vision Next Evening Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	.394	2	.197	.570	.570
GOGGLE	.367	1	.367	1.060	.309
MOON	.027	1	.027	.079	.780
2-Way Interactions					
GOGGLE MOON	.027	1	.027	.079	.780
Explained	.417	3	.139	.402	.753
Residual	13.833	40	.346		
Total	14.250	43	.331		

Analysis of Variance
Headaches Test Night

Tests of Significance for Blurred Vision Next Evening Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	.136	2	.068	.032	.969
GOGGLE	.109	1	.109	.051	.822
MOON	.027	1	.027	.013	.911
2-Way Interactions					
GOGGLE MOON	2.209	1	2.209	1.033	.315
Explained	2.409	3	.803	.376	.771
Residual	85.500	40	2.138		
Total	87.909	43	2.044		

Analysis of Variance
Headaches Next Evening

Tests of Significance for Headaches Next Evening Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	2.462	2	1.231	1.445	.248
GOGGLE	2.128	1	2.128	2.497	.122
MOON	.334	1	.334	.392	.535
2-Way Interactions					
GOGGLE MOON	.061	1	.061	.072	.790
Explained	2.553	3	.851	.999	.403
Residual	34.083	40	.852		
Total	36.636	43	.852		

Analysis of Variance
Eyestrain Test Night

Tests of Significance for Eyestrain Test Night Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	.888	2	.444	.193	.825
GOGGLE	.012	1	.012	.005	.943
MOON	.876	1	.876	.380	.541
2-Way Interactions					
GOGGLE MOON	1.603	1	1.603	.696	.409
Explained	2.729	3	.910	.395	.757
Residual	92.067	40	2.302		
Total	94.795	43	2.205		

Analysis of Variance
Eyestrain Next Evening

Tests of Significance for Eyestrain Next Evening Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	4.173	2	2.086	3.137	.054
GOGGLE	3.927	1	3.927	5.906	.020
MOON	.245	1	.245	.369	.547
2-Way Interactions					
GOGGLE MOON	.245	1	.245	.369	.547
Explained	4.377	3	1.459	2.194	.104
Residual	26.600	40	.665		
Total	30.977	43	.720		

Analysis of Variance
Tight Neck Muscles Test Night

Tests of Significance for Tight Neck Muscles Test Night Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	9.729	2	4.864	2.364	.107
GOGGLE	.728	1	.728	.354	.555
MOON	9.001	1	9.001	4.374	.043
2-Way Interactions					
GOGGLE MOON	2.819	1	2.819	1.370	.249
Explained	13.570	3	4.523	2.198	.103
Residual	82.317	40	2.058		
Total	95.886	43	2.230		

Analysis of Variance
Tight Neck Muscles Next Evening

Tests of Significance for Tight Neck Muscles Next Evening Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	.694	2	.347	.185	.832
GOGGLE	.682	1	.682	.363	.550
MOON	.012	1	.012	.006	.936
2-Way Interactions					
GOGGLE MOON	1.467	1	1.467	.782	.382
Explained	2.148	3	.716	.382	.767
Residual	75.033	40	1.876		
Total	77.182	43	1.795		

Analysis of Variance
Stiff Whole Body Test Night

Tests of Significance for Stiff Whole Body Test Night Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	5.808	2	2.904	1.976	.152
GOGGLE	5.473	1	5.473	3.725	.061
MOON	.334	1	.334	.227	.636
2-Way Interactions					
GOGGLE MOON	3.607	1	3.607	2.454	.125
Explained	9.648	3	3.216	2.188	.104
Residual	58.783	40	1.470		
Total	68.432	43	1.591		

Analysis of Variance
Stiff Whole Body Next Evening

Tests of Significance for Stiff Whole Body Next Evening Using UNIQUE Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
Main Effects	3.715	2	1.858	.890	.419
GOGGLE	3.712	1	3.712	1.779	.190
MOON	.003	1	.003	.001	.970
2-Way Interactions					
GOGGLE MOON	.367	1	.367	.176	.677
Explained	4.079	3	1.360	.652	.587
Residual	83.467	40	2.087		
Total	87.545	43	2.036		

APPENDIX H

QUESTIONNAIRE C

QUESTIONNAIRE C

1. What were the major sources of the subjects' discomfort? List each source in order of its contribution to discomfort. What would be a remedy for each source listed?

2. Headaches (Write "N/A" where appropriate.)

What appeared to be the sources of your headaches during test nights?

What appeared to be the sources of your headaches during the next day?

What appeared to be the sources of your <u>subjects'</u> headaches during test nights?

3. List any features of the monocular goggle that appeared to make it more uncomfortable than the biocular goggle.

4. List any features of the biocular goggle that appeared to make it more uncomfortable than the monocular goggle.

5. Write any additional comments you may have.

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13. ABSTRACT *(Maximum 200 words)*

Forty-four military participants were tested in a field experiment to compare the relative discomfort experienced when monocular versus biocular night vision goggles (NVGs) were worn for an extended period of time. Participants traversed wooded terrain to reach various stations where they performed a variety of military and field craft tasks. The total test time was 4 hours. The participants rated their psychological and physiological feelings of discomfort at the completion of the test and again the following evening. Objective measures of NVG optical adjustments were also recorded.

The participants who wore the biocular goggle reported a higher incidence of tight neck muscles than did the participants who wore the monocular goggle. However, no other significant differences in discomfort were found that could be attributed to the ocular configuration of the goggles. All participants complained about discomfort from the head harness.

14. SUBJECT TERMS

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comfort	monocular	off-road mobility	
extended use	night vision goggles	resolution	

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